METHOD AND APPARATUS FOR PROVIDING AN EARLY WARNING OF THERMAL DECAY IN MAGNETIC STORAGE DEVICES

Priority is claimed from U.S. Provisional Patent Application No. 60/223,444, filed August 4, 2000 entitled "METHODS OF EARLY WARNINGS FOR THERMAL DECAY IN MAGNETIC DEVICES," which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to magnetic storage devices. More particularly, the present invention relates to the early detection of thermal decay in magnetic storage devices.

BACKGROUND OF THE INVENTION

Computer disk drives store digital information on magnetic disks. The magnetic disks are generally coated with a magnetic material capable of changing the direction of its magnetic orientation in response to an applied magnetic field. Information is stored on the magnetic disks as a series of magnetic transitions. Typically, the information is stored on each disk in concentric tracks that are divided into servo sectors and data sectors. Information is written to or read from a disk by a transducer head mounted on an actuator arm that is capable of moving the transducer head radially over the disk. The movement of the actuator arm allows the transducer head to access different tracks. The disks are rotated by a spindle motor at a high speed, allowing the transducer head to access different sectors within each track on the disk. The transducer head may include integrated read and write heads.

In response to the increasing need to store large amounts of digital data in connection with computer systems, magnetic storage devices have utilized increased data storage densities. In order to support high data densities, the magnetic material of the magnetic disks must be provided in a very thin layer. In addition, high data densities require magnetic material with a small grain size. A thin layer and a small grain size reduce noise, and allow magnetic transitions to be more closely spaced together. However, the energy required to switch the magnetization of the material is decreased when the magnetic material has a small grain size and is provided in a thin layer. Accordingly, as the grain size and the layer thickness of the magnetic material has decreased, the material has become more susceptible to data loss due to thermal decay.

Thermal decay is related to the ratio of the energy barrier that must be crossed in order to switch the magnetization of the magnetic material of a magnetic disk to the thermal energy of the surrounding environment. In general, as the energy in the environment becomes more nearly equal to this energy barrier, thermal decay is more likely to occur. A magnetic disk having only a thin layer of magnetic material is particularly susceptible to thermal decay because the energy required to switch the magnetization of a portion of that disk is low. In addition, when data is stored at high densities, the area of the disk used to store a bit of information as a particular magnetic polarity (*i.e.* a bit cell) is small. Therefore, the energy required to switch the magnetization of a bit cell is reduced with increased areal densities. Furthermore, as grain sizes have been reduced, the anisotropic energy associated with each grain has also

been reduced. As the anisotropic energy of each grain becomes nearer to the ambient thermal energy in a disk drive, information stored on the magnetic disk is more likely to be lost due to thermal decay.

As will be understood by those skilled in the art, the anisotropic energy of a grain is the fixed amount of energy required to maintain a stored direction of magnetization in the magnetic material, and is equal to the anisotropic energy density, Ku, times the volume of the grain, V. A thermal instability ratio is defined as the anisotropic energy divided by the thermal energy, kT, and is given by the formula KuV/kT, which should be greater than 50 in a conventional disk drive for adequate thermal stability. Ultimately, if a certain number of grains change their direction of magnetization due to thermal effects, the amplitude of a signal produced in the transducer head when the affected area is read will be decreased. Once the stored information decays beyond a threshold level, it will be impossible to properly read data written to the disk with the read head. In particular, the loss in the amplitude of a signal produced in the transducer head will cause data to be lost.

In order to address the effects of thermal decay, various measures have been taken. For example, error correction code may be used to restore data lost through processes such as thermal decay. However, the ability of error correction code to restore lost data is limited. In addition, the use of error correction code results in decreased user data density.

Attempts have also been made to produce magnetic disks having grains with large

anisotropic energies. However, increasing the anisotropic energy of the grains generally requires larger grain sizes. As mentioned above, a larger grain size increases the noise of a signal produced by data stored on the magnetic disk. In particular, the transition noise is increased. Increased noise reduces the signal to noise ratio, and may adversely affect the bit error rate of the disk drive. In addition, if the anisotropic energy is increased by increasing the anisotropic constant (Ku), the coersivity (Hc) is also increased, and it becomes more difficult to write transitions to the magnetic disk.

Disk drive manufacturers have also limited the effects of thermal decay by requiring the magnetic material on a magnetic disk to be at least a certain minimum thickness, thereby increasing the volume of grains within a bit cell. However, as with increased grain sizes, increasing the thickness of the magnetic material increases noise when data is read from the magnetic disk.

For the above-stated reasons, it would be desirable to provide a method and an apparatus that allowed for increased data storage densities, without losing data due to thermal decay. In particular, it would be desirable to provide a method and an apparatus capable of providing an early warning of thermal decay. In addition, it would be advantageous to provide such a method and apparatus that are reliable in operation and that are inexpensive to implement.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and an apparatus for providing an early warning of thermal decay in connection with magnetic storage media are

provided. The present invention generally allows thermal decay to be detected before such decay has led to data loss from the magnetic storage device. In particular, the present invention allows remedial action to be taken before thermal decay results in data loss.

In accordance with one embodiment of the present invention, a test pattern determined to have a relatively high susceptibility to thermal decay is written to a magnetic storage device. For example, the test pattern may be written to a smaller volume of magnetic material than would be used if that test pattern were written as normal user data. This may be achieved by writing the test pattern using smaller bit cells, by writing the test pattern to an area of the disk having a thinner than average layer of magnetic material, or by using a combination of these approaches.

In accordance with a further embodiment of the present invention, the test pattern is written at a data frequency associated with a track or zone located at an outside diameter of a magnetic storage disk, but is written on a track located towards an inner diameter of the disk. Such an embodiment is particularly useful in connection with a longitudinal recording scheme.

In accordance with yet another embodiment, a gray code pattern of transitions is written to the outside diameter of the disk. Alternatively or in addition, the test pattern is written at a data frequency associated with a track or zone located at an inside diameter of a magnetic storage disk, but is written on a track located towards an outer diameter of the disk. Such an embodiment is particularly useful in connection with a perpendicular

recording scheme.

In accordance with another embodiment of the present invention, the test pattern utilizes a pattern of transitions that have been determined to be particularly susceptible to thermal decay. Such a test pattern may be developed by design engineers in consideration of the magnetic and mechanical properties of the storage device. In addition, automated testing of a plurality of test patterns to select a pattern that is particularly susceptible to thermal decay in connection with a particular storage device or family of storage devices may be performed.

In accordance with still another embodiment of the present invention, a portion of the media upon which data is stored that is particularly susceptible to thermal decay is identified. For example, an area of the disk having an especially thin layer of magnetic material is identified. This area of the disk may be identified by reading the amplitudes of selected servo information, such as automatic gain control (AGC) fields. A sector associated with a piece of monitored servo sector information having a low amplitude is generally more susceptible to thermal decay, for example because it is associated with an area of the disk in which the layer of magnetic material is thinner. Accordingly, the volume of magnetic material in the area is relatively low, and the area is thus more susceptible to the effects of thermal decay. In accordance with yet another embodiment of the present invention, an area of a magnetic storage disk that is particularly susceptible to the effects of thermal decay is created on purpose. For example, an area of the disk corresponding to one or more sectors or tracks may be provided with a layer of magnetic

material that is thinner than the layer of magnetic material in areas of the disk intended for storing normal user data. A test pattern may then be written to the area identified as being more susceptible to thermal decay or created to be more susceptible to thermal decay.

According to still another embodiment of the present invention, a pattern that has been determined to be particularly susceptible to thermal decay may be written to an area of the disk that is particularly susceptible to thermal decay.

Following the selection of a test pattern and/or a test pattern location, the test pattern is written to the storage device. The test pattern is then read, and the amplitude of the signal produced by reading the test pattern is stored. In order to detect an indication of thermal decay, the test pattern is later read again, and the amplitude of the signal thus obtained is observed. The observed amplitude is compared to the stored amplitude. If the stored amplitude is greater than the observed amplitude, a signal warning of thermal decay is generated. In accordance with still another embodiment of the present invention, a signal warning that thermal decay has been detected is generated if the stored amplitude is greater than the observed amplitude plus a marginal value.

In response to a signal warning of thermal decay, the storage device may automatically take measures to prevent data loss. For example, data stored in the device may be rewritten. Rewriting the data protects against data loss due to thermal decay by realigning magnetic domains that may have been altered due to the effects of thermal decay.

Additional advantages of the present invention will become readily apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation of top view of a conventional computer disk drive, with the cover removed;

Fig. 2 is a diagrammatic representation of a magnetic storage disk;

Fig. 3A depicts magnetic polarizations in a cross section of a track contained on a disk according to a longitudinal recording scheme;

Fig. 3B depicts the magnetization of the cross section of a track illustrated in **Fig. 3A**;

Fig. 3C illustrates an example voltage potential produced in the channel as a result of the pattern of magnetization depicted in **Fig. 3B**;

Fig. 4A depicts magnetic polarizations in a cross section of a track contained on a disk according to a perpendicular recording scheme;

Fig. 4B depicts the magnetization of the cross section of a track illustrated in **Fig. 4A**;

Fig. 4C illustrates an example voltage potential produced in the channel as a result of the pattern of magnetization depicted in Fig. 4B;

Fig.5 is a functional flow diagram illustrating the operation of a system in accordance with an embodiment of the present invention; and

Fig. 6 is a functional flow diagram illustrating the operation of still another embodiment of the present invention.

DETAILED DESCRIPTION

With reference now to **Fig. 1**, a typical disk drive **100** is illustrated. The disk drive **100** includes a base **104** and magnetic disks **108** (only one of which is shown in **Fig. 1**). The magnetic disks **108** are interconnected to the base **104** by a spindle motor (not shown) mounted within or beneath the hub **112** such that the disks **108** can be rotated relative to the base **104**. The magnetic disk **108** is generally formed from a film of magnetically hard material deposited on a substrate. For example, the disk **108** may be formed by depositing a metal film on a rigid substrate.

Actuator arm assemblies **116** (only one of which is shown in **Fig. 1**) are interconnected to the base by a bearing **120**. Actuator arm assemblies **116** each include a transducer head **124** at a first end, to address each of the surfaces of the magnetic disks **108**. The transducer heads **124** typically include read and write elements (not shown). A voice coil motor **128** pivots the actuator arm assemblies **116** about the bearing **120** to radially position the transducer heads **124** with respect to the magnetic disks **108**. By changing the radial position of the transducer heads **124** with respect to the magnetic disks **108**, the transducer heads **124** can access different tracks or cylinders **132** on the magnetic disks **108**. The voice coil motor **128** is operated by a controller **136** that is in turn operatively connected to a host computer (not shown). A channel **140** processes information read from the magnetic disk **108** by the transducer heads **124**.

With reference now to **Fig. 2**, a typical arrangement of data tracks **132** on a magnetic disk **108** is illustrated. Usually, the data tracks **132** are divided into data fields **204a-h** with a servo sector **208a-h** between one or more of the data fields **204a-h**. Generally, the data fields **208a-h** are used for storing data, while the servo sectors **208a-h** are used for storing servo information that is used to provide the transducer head **124** with positioning information. Typically, at least some of the information contained in the servo sectors **208a-h** is written during the servo track writing process, and the portions of the servo sectors **208a-h** containing such information generally cannot be written to after the disk **100** is assembled. In particular, the servo sectors **208a-h** provide the transducer heads **124** with information concerning their position over the magnetic disks **108**, including servo sector position bursts and embedded runout correction (ERC) information fields, and information used to calibrate the channel **140**, including automatic gain control information (AGC) fields. Data and other information can be stored in tracks **132** according to either longitudinal or perpendicular recording schemes.

The tracks **132** on the magnetic disk **108** may further be divided into a plurality of zones **212a-c**. The grouping of tracks **132** into a plurality of zones **212** facilitates the efficient storage of data on the disk **108**. For example, because the disk **108** rotates at a constant speed, user data may be stored in tracks **132** associated with a zone (*e.g.,* zone **212a**) located towards an outside diameter of the disk **108** at a relatively high frequency, while maintaining adequate disk area to reliably store the data as magnetic transitions. In contrast, user data generally cannot be written to a track **132** within a zone (*e.g.,* **212c**)

located towards an inner diameter of the disk **108** at the same high frequency as user data for storage in a track in a zone at an outer diameter, such as zone **212a**. This is because at the inside diameter, insufficient disk area would be then used in connection with the magnetic transitions used to store user data reliably.

Although the magnetic disk **108** illustrated in **Figs. 1** and **2** is shown as having a relatively small number of data tracks **132**, data fields **204**, servo sectors **208** and zones **212**, it can be appreciated that a typical computer disk drive **100** contains a very large number of data tracks **132**, data fields **204**, and servo or hard sectors **208**, and may have a greater or lesser number of zones **212**. For example, computer disk drives **100** having over 30,000 tracks per inch and 120 servo sectors are presently available.

In addition, alternate configurations of magnetic disks **108** are possible. For example, in a computer disk drive **100** having several magnetic disks **108**, a surface of one of the disks **108** may be dedicated to servo information, while the surfaces of the remaining disks may be used exclusively to store data.

With reference now to **Fig. 3A**, a portion of a track **132** to which a repeated pattern of data has been written according to a longitudinal recording scheme is schematically illustrated. The section of track **132** illustrated in **Fig. 3A** can be seen to contain a number of bit cells **300a-l**. A bit cell is defined as the shortest length of track **132** that can encode a bit of user data, and corresponds to the minimum length of track **132** used to store a magnetic transition. An arrow in a bit cell **300** indicates the magnetic polarity of the bit cell **300**. If the magnetization of a bit cell **300** in a given direction is a

1 and the magnetization of a bit cell in the opposite direction is a 0, it can be seen that the pattern of data produced by the pattern of magnetic transitions illustrated in **Fig. 3A** is such that each character is alternately repeated. That is, the pattern of bits is 1, 1, 0, 0, 1, 1, 0, 0 . . . as shown in **Fig. 3A**. In a 1T data pattern, the bits alternate 1, 0, 1, 0 . . . .

With reference now to **Fig. 3B**, a pattern of magnetic polarities corresponding to the pattern of magnetization shown in **Fig. 3A** is illustrated. As shown in **Fig. 3B**, a pattern of magnetic polarities written to a track **132** effectively forms a series of magnets **304** in the track **132**. As can be appreciated, at the boundaries of the magnets **304**, which correspond to boundaries between bit cells **300** containing opposite magnetic polarities, the lines of magnetic flux produced by the magnets **304** will be normal to the surface of the disk **108** in the vicinity of the disk surface. In addition, the direction of the magnetic flux will be substantially parallel to the surface of the disk **108** in areas away from magnetic transitions in a longitudinal recording scheme. As can be appreciated, a transducer head **124** following a track **132** in close proximity to the surface of the disk **108** can sense these changes in magnetic flux. As will be understood by those of ordinary skill in the art, the changes in magnetic flux can be used to produce a voltage or a change in resistance in a read element of the transducer head **124**.

With reference now to **Fig. 3C**, a wave form **308** produced in the channel **140** as the transducer head **124** passes through the magnetic flux produced by the magnetization illustrated in **Fig. 3A** is depicted. In general, the wave form **308** is expressed in the channel as a voltage or current signal. Peaks **312** in the wave form **308** occur

periodically. By comparing **Figs. 3A** and **3C**, it can be appreciated that the peaks **312** correspond to magnetic transitions written on the track **132**. If magnetic domains within a bit cell **300** have their direction changed due to thermal decay, the amplitude observed at the peaks **312** in the wave form **308** will be reduced.

With reference now to **Fig. 4A**, a portion of track **132** to which a repeated pattern of data has been written according to a perpendicular recording scheme is illustrated. As will be appreciated by a comparison of the portion of track **132** illustrated in **Fig. 3A** to the portion of track illustrated in **Fig. 4A**, the direction of magnetization of bit cells in **Fig. 4A** is perpendicular to the direction of travel of the track **132** relative to the transducer head **124**. The series of bits encoded by the pattern of magnetization of the bit cells **400a-l** illustrated in **Fig. 4A** is the same as in **Fig. 3A.**

Fig 4B depicts a pattern of magnetic polarities corresponding to the pattern of magnetization illustrated in **Fig. 4A**. As will be appreciated from a comparison of the relevant figures, the magnets **404** in the perpendicular recording scheme illustrated in **Fig. 4B** are rotated 90° with respect to the magnets **304** of **Fig. 3B**.

With reference now to **Fig. 4C**, a wave form **408** produced in the channel **140** as the transducer head **124** passes through the magnetic flux produced by the magnetization illustrated in **Fig. 4B** is depicted. In general, the peaks **412** correspond to those portions of the track **132** with respect to which the lines of magnetic flux are perpendicular to the relative direction of travel of the transducer head **124**. As is the case with a longitudinal recording scheme (e.g., **Figs. 3A, 3B and 3C**), the amplitude observed at the peaks **412**

will be reduced if magnetic domains within a bit cell **400** have their direction changed due to thermal decay.

The inventors of the present invention have recognized that particular sequences of data and the location on the magnetic disk 108 to which data is written affect the susceptibility of the data to thermal decay. In general, with respect to a longitudinal recording scheme, a sequence of data featuring a relatively high number of magnetic transitions, such as a 1T pattern, utilizes a relatively small continuous volume of magnetic material for each magnetic polarization. Because fewer grains of magnetic material are aligned in the same direction, a change in the orientation of relatively few of the grains due to thermal decay has a relatively large effect. Also, if a sequence of data is written at a higher than normal frequency in a longitudinal recording scheme, the volume of each bit cell (e.g., bit cells **300** in **Fig. 3A**) will be smaller than the bit cells used to store regular user data. Therefore, such a sequence, which will have a relatively high data density, is again more likely to show the effects of thermal decay.

With respect to a perpendicular recording scheme, a sequence featuring a relatively low number of magnetic transitions, for example a 12T or 24T pattern, is more susceptible to thermal decay. In addition, a pattern written towards the outside diameter of a disk, where individual bit cells (*e.g.* bit cells **400** in **Fig. 4A**) are less crowded, is more susceptible to thermal decay. The likelihood that thermal decay will become apparent can also be increased by writing a test pattern at a frequency normally associated with a track **132** or zone **212** located towards the inside diameter of a disk **108** to a track

132 or zone **212** located towards an outside diameter of the disk **108** (*i.e.* by writing a pattern having a relatively low data density). In general, in a perpendicular recording scheme, the likelihood that thermal decay will become evident can be increased by magnetizing a relatively small area of a track **132** in a first direction, and magnetizing the surrounding areas of the track **132** in a second direction.

With respect to both longitudinal and perpendicular recording schemes, an area of the disk **108** having a thinner than normal layer of magnetic material will result in bit cells **300 or 400** having a smaller than normal volume of magnetic material. Therefore, a test pattern written to an area identified as having a particularly thin layer of magnetic material will be more susceptible to thermal decay. Thinner areas of a disk **108** may be the result of normal manufacturing variations, or they may be created intentionally during manufacture of the disk **108.**

With reference now to **Fig. 5**, a flow chart illustrating the operation of an embodiment of the present invention is illustrated. Initially, at step **500**, a test pattern is written to the magnetic disk **108**. In general, the test pattern is selected so that it is more susceptible to thermal decay than is normal user data.

With respect to a longitudinal recording scheme, the test pattern is preferably more susceptible to thermal decay than a 1T pattern written as normal user data. For example, the test pattern may be written at a frequency that is higher than the frequency used to write user data to the same or a similar track **132**, and thus at a relatively high data density. The test pattern may be written at a higher frequency than that used for

normal user data by writing the test pattern to a track **132** included in a zone **212** (*e.g.*, zone **212c** of **Fig. 2**) located towards an inner diameter of the disk **108** but using a data frequency that would normally be used to write user data to a track **132** associated with a zone **212** (*e.g.*, zone **212a** of **Fig. 2**) located towards an outer diameter of the disk **108**. As noted above, in a longitudinal recording scheme such a pattern will tend to be more susceptible to the effects of thermal decay than user data, because the magnetic transitions are then written to a shorter length of track **132** than is user data, and therefore are contained in a relatively small volume of magnetic material.

With respect to a perpendicular recording scheme, the test pattern may be written so that the frequency of magnetic transitions is relatively low. For example, in accordance with one embodiment of the present invention, the test pattern is written as a 12T pattern. In accordance with still another embodiment of the present invention, the test pattern is written as a 24T pattern. In addition, the test pattern may be written at a lower frequency (and thus at a lower data density) than that used for normal user data by writing the test pattern to a track **132** included in a zone **212** (*e.g.*, zone **212a** of **Fig. 2**) located towards an outside diameter of the disk **108** but using a data frequency that would normally be used to write user data to a track associated with a zone **212** (*e.g.*, zone **212c** of **Fig. 2**) located towards an inner diameter of the disk **108**. A pattern of data written according to any of these embodiments in connection with a perpendicular recording scheme will be more likely to show the effects of thermal decay than user data, because bit cells **400** magnetized in a first direction are isolated among bit cells **400** magnetized in

a second direction. Therefore, it is more likely that grains included in the bit cell **400** magnetized in a first direction will be flipped due to the effects of thermal decay.

In accordance with still another embodiment of the present invention, the test pattern may involve the writing of a series of magnetic transitions that is particularly susceptible to thermal decay. For example, a test pattern may be developed in which, due to the particular pattern of magnetic transitions, the magnetic domains that comprise the magnetic transitions are particularly unstable. Such a test pattern may be selected, at least in part, utilizing an automated process in which a plurality of evaluation test patterns are written to a disk **108**. The disk **108** may then be stressed, for example, by subjecting the disk **108** to elevated temperatures. The evaluation test pattern with respect to which the greatest amount of thermal decay is evident may then be selected as a thermal decay test pattern for writing to all surfaces of the disk **108** included in a drive **100**. Alternatively, such a determination may be made in connection with a family of disk drives **100** by analyzing a particular example disk drive **100**. An example of such a test pattern in connection with a longitudinal recording scheme is a pattern that includes a combination of 2T and 1T patterns. In connection with a perpendicular recording scheme, such a test pattern may include a combination of 24T and 12T patterns.

At step **504**, the amplitude of a signal produced in the channel **140** from reading the test pattern is measured. That amplitude, which will be used as a reference amplitude, is then stored (step **508**). The amplitude may be stored in the disk drive **100** itself, for example on the magnetic storage disk **108**, or in memory (not shown) associated with the

disk drive **100**. In general, steps 500-508 may be performed before the disk drive **100** is delivered to the end user.

At step **512**, a determination is made as to whether the drive **100** should be tested for indications of thermal decay. For example, testing of the drive **100** may be indicated after a predetermined period of time has elapsed. For instance, a disk drive may initiate a self test for indications of thermal decay every two weeks. Alternatively or in addition, testing for thermal decay may be initiated in response to a user's instruction to begin such testing. Testing may also be indicated based on a combination of the amount of time that has elapsed since the last test was performed, and the operating temperature experienced by the disk drive **100**. Once it has been determined that the disk drive **100** should be tested for indications of thermal decay, the test pattern is read from the disk **108** to obtain an observed amplitude of the signal produced in the channel **140** by the test pattern (step **516**).

At step **520**, a determination is made as to whether the stored reference amplitude is greater than the observed amplitude. In order to reduce the sensitivity of the disk drive **100** to normal variations in the observed amplitude, the comparison may be made between the stored amplitude and the observed amplitude plus a marginal value. In general, the marginal value should be large enough that a small attenuation of the observed signal, such as may be caused by noise in the channel **140**, does not cause a thermal decay warning signal to be generated. If the stored amplitude is greater than the observed amplitude plus a marginal amount, a thermal decay warning signal is generated

(step **524**).

In response to a thermal decay warning signal, the hard disk drive **100** may take steps to ensure the integrity of user data stored in the disk drive **100**. For example, data stored in the disk drive **100**, or on a surface of a disk **108** in connection with which an indication of thermal decay has been detected, may be rewritten. Alternatively, the warning may be communicated to the user, and the user may decide what action should be taken to ensure the integrity of the data.

With reference now to **Fig. 6**, a functional flow diagram in connection with another embodiment of the present invention is illustrated. Initially, at step **600**, the amplitudes of automatic gain control (AGC) fields are measured in order to obtain the amplitudes of signals derived from those fields. At step **604**, a test pattern is written to a sector of track **132** associated with an AGC field having a low amplitude. In general, a sector associated with an AGC field having a relatively low amplitude will be more susceptible to thermal decay, as described above. For example, a low AGC field amplitude may indicate an area of the disk **108** in which the layer of magnetic material is particularly thin. In accordance with an embodiment of the present invention, an AGC field amplitude may be considered low if it is at least about 10% less than an average AGC field amplitude. In accordance with another embodiment of the present invention, the AGC field amplitude may be considered low if it is less than about 5% less than an average AGC field amplitude. At step **608**, the amplitude of a signal produced by reading the test pattern is measured. The measured amplitude is then stored (step **612**). In

general, steps 600-612 may be performed prior to delivery of the disk drive **100** to the end user.

Next, a determination is made as to whether testing for indications of thermal decay should be performed (step **616**). As with the previous embodiment described in connection with **Fig. 4**, testing may be indicated after a predetermined period of time has elapsed, or after an instruction to test for thermal decay has been received from the user. If it has been determined that testing for thermal decay should proceed, the test pattern is read to obtain an observed amplitude of a signal produced by the test pattern in the channel **140** (step **620**). The stored amplitude is then compared to the observed amplitude. If the stored amplitude is greater than the observed amplitude plus a marginal amount (step **624**), a thermal decay warning signal is generated (step **628**). If the stored amplitude is not greater than the observed amplitude plus a marginal amount, the drive returns to step **616** to await the next instruction to perform testing in connection with the detection of thermal decay.

In accordance with another embodiment of the present invention, a thinned area of the magnetic disk **108** may be purposefully created during manufacture of the magnetic disk **108**. According to such an embodiment, if the thinned area's location is known in advance, a test pattern of data may be written to that area without performing additional steps to locate the thinned area. Alternatively, additional steps, such as searching for an area associated with a relatively weak AGC field, may be used to confirm or locate an intentionally thinned area of the magnetic disk **108**. In accordance with an embodiment

of the present invention, the intentionally thinned area is at least about 5% thinner than an average magnetic layer thickness. In accordance with yet another embodiment of the present invention, the intentionally thinned area is at least about 3% thinner than an average magnetic layer thickness.

In accordance with another embodiment of the present invention, a test pattern can be used in connection with a disk drive's **100** internal diagnostic procedures to provide an early warning of thermal decay. For example, the voltage gain amplitude (VGA) register value obtained when the transducer head **126** is reading the test pattern can be stored. When testing of the disk drive **100** is desired, the test pattern is again read and the VGA value obtained read is compared to the stored VGA value. If the observed VGA value is 10% less than the stored VGA value, a thermal decay warning signal may be generated.

With respect to any of the embodiments of the present invention, testing for thermal decay may be performed in connection with each surface of each disk **108** included in a disk drive **100**. Furthermore, certain of the described embodiments may be combined in a single, additional embodiment. For example, a test pattern that has been determined to be particularly susceptible to thermal decay may be written to an area of a disk surface that has been identified as being particularly susceptible to thermal decay. In addition, although the above description has used a hard disk drive as an example, the present invention is equally applicable to other types of magnetic storage devices.

The foregoing discussion of the invention has been presented for purposes of illustration and description. Further, the description is not intended to limit the invention

to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, within the skill and knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain the best mode presently known of practicing the invention and to enable others skilled in the art to utilize the invention in such or in other embodiments and with various modifications required by their particular application or use of the invention. It is intended that the appended claims be construed to include the alternative embodiments to the extent permitted by the prior art.